FOREWORD

The results presented in this publication were unexpected and, at this point, provide more questions than answers. First priority must be given to identifying the factor(s) responsible for the performance of animals receiving cement kiln dust. In the meantime, these data suggest that some well-established views on feeding regimes for ruminant livestock would merit reconsideration.

The broad significance of this study, as well as ongoing studies, on the use of a specific source of cement kiln dust remains to be established. The findings reinforce the view that many of our most exciting basic research investigations are initiated in response to the findings of applied research or, in this case, in response to farmer experience confirmed in an applied feeding experiment.

CEMENT KILN DUST IN DIETS FOR FINISHING STEERS

W. E. Wheeler and R. R. Oltjen[1]

SUMMARY

A trial was conducted with 14 finishing steers (average initial weight, 342 kg) to study the influence of cement kiln dust on feedlot performance, ruminal characteristics, and carcass merit. Complete mixed diets consisted of 53 percent forage and 47 percent concentrate, on a dry-matter basis. The control diet (12 percent crude protein) was formulated to meet the National Research Council nutrient requirements for finishing steers. The experimental diet (8 percent crude protein) contained the same forage-to-concentrate ratio and 3.5 percent cement kiln dust, on a dry basis, but no supplemental protein, minerals, or salt. Steers fed the diet containing cement kiln dust had a 0.29 kg higher (1.04 vs. 1.33 kg) average daily gain and a 21 percent improved (10.89 vs. 8.62 kg) feed/gain ratio during the 112-day trial. Carcasses from steers fed cement kiln dust had 0.7 cm more fat over the rib, a higher marbling score, and a higher grade (high choice vs. high good) than the control group. There were no differences in weight of empty reticulo-rumen, heart, liver, kidneys, or spleen when expressed per unit empty body weight. Reticulo-rumen ingesta, intestinal ingesta, and fecal pH values for steers fed cement kiln dust were near 6.9 and about 0.5 pH unit higher than those of the control group.

INTRODUCTION

Portland cement consists of the oxides of calcium, silicon, aluminum, and iron which have the ability to harden into a stonelike material. The basic raw ingredients for making Portland cement are: (1) a calcium carbonate source such as limestone, cement rock, chalk, or oyster shell; (2) a silica source such as sand, quartzite, or Fuller's earth; (3) an alumina source such as clay, shale, slag, aluminum ore tailings, or fly ash; and (4) an iron source such as iron ore, iron oxide, blast furnace flue dust, or iron pyrites (Anonymous, 1971). These raw ingredients are finely ground and then cured in a rotary kiln at 1500°C for 4 hours.

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[1]Research Animal Scientists, Ruminant Nutrition Laboratory, Nutrition Institute, Beltsville, Md. 20705. R. R. Oltjen is now Director, U.S. Meat Animal Research Center, ARS, USDA, Clay Center, Nebr. 68933. The authors acknowledge L. H. Barr, Jr., D. G. Barnett, and S. E. Floyd of Polk County, Georgia, for supplying the cement kiln dust used in this study.

The hot gases leaving the kiln contain considerable quantities of particulate material that cannot be introduced directly into the environment. Consequently, cement manufacturers are required to remove at least 96 percent of the particulate emissions by passing the gases from the kiln through dust-settling chambers, cyclone separators, electrostatic precipitators or a combination of these techniques (Kreichelt et al., 1967). Davis and Hooks (1975) have estimated that about 325 tons of cement kiln dust are collected daily by each Portland cement plant in the United States. However, only small amounts of kiln dust can be returned to the cement manufacturing process.

Most cement kiln dust is stored in open piles on the ground or in abandoned limestone quarries. The rainwater runoff from these exposed piles of kiln dust is highly alkaline (pH 11.5 to 12.5). Consequently, this runoff can contribute to pollution of streams and ground water unless collected and treated (Davis and Hooks, 1975). Cost of handling cement kiln dust and treatment of runoff water make disposal of the dust economically and environmentally unattractive.

There have been some agricultural uses of cement kiln dust as a liming material. Whittaker et al. (1959) and Carrol et al. (1964) reported that cement kiln dust had about 80 percent of the soil-neutralizing capacity of lime and about the same liming qualities as pulverized limestone. Currently only small amounts of cement kiln dust are used as an agricultural liming material.

We became aware of undocumented reports from Georgia of improved gains by growing steers fed a diet consisting of soybean hay, corn grain, and cement kiln dust. The mineral analysis of cement kiln dust, as reviewed by Davis and Hooks (1975), indicated that the dust contained not only calcium but also appreciable amounts of several trace minerals known to be essential to ruminants (National Research Council, 1976). Furthermore, cement kiln dust has a high buffering capacity that could be beneficial to digestion in the gastrointestinal tract of ruminants (Wheeler and Noller, 1976).

We know of no reports in the literature of cement kiln dust used in the diet of livestock. Therefore, we felt the mineral content and buffer capacity of this environmental pollutant warranted investigation into its potential as a feed ingredient for ruminants. Consequently, a study was begun to examine the influence of cement kiln dust on the performance of finishing steers fed a relatively high forage diet. This report contains results of the first experiment.

EXPERIMENTAL PROCEDURE

A nested factorial experimental design was used for a feeding trial with eight Angus (average weight, 360 kg), four Holstein (average weight, 331 kg), and two Charolais (average weight, 319 kg) steers paired by breed and weight. Steers from each pair were allotted randomly to each of the two dietary treatments in table 1.

Complete mixed diets (table 1) consisted of 53.2 percent forage and 46.8 percent concentrate on a dry basis. The forage portion contained equal parts

of dry matter from fescue and timothy hays. The control diet (table 1) was formulated to provide, on a dry basis, a calculated 12.0 percent crude protein, 0.4 percent calcium, 0.3 percent phosphorus, and 1.0 percent trace mineral salt. Georgia farmers previously had indicated that steers responded to diets consisting only of chopped soybean hay, ground snapped corn, and cement kiln dust. Therefore, all supplemental protein, minerals, and salt were omitted, and 3.5 percent cement kiln dust was added to the experimental diet (table 1).

TABLE 1.--Composition and analysis of experimental diets

Item	Internat'l Ref. No.	Diet[1]	
		Control	Kiln dust
		-------Percent---------	
Ingredient:			
Fescue, hay, s-c, grnd[2]	1-01-912	26.6	26.6
Timothy, hay, s-c, grnd, gr 2 US[2]	1-04-882	26.6	26.6
Corn, dent yellow, grain, cracked	4-02-935	34.0	35.4
Soybean, seed, solv-extd, grnd, 7% fiber	5-04-604	3.7	----
Molasses, sugarcane, mn 48% invert sugar	4-04-696	7.8	7.8
Limestone, grnd, mn 33% Ca	6-02-632	.1	----
Calcium phosphate, dibasic[3]	6-01-080	.1	----
Trace mineral salt		1.0	----
Cement kiln dust		----	3.5
Vitamin A and D premix[4]		.1	.1
Chemical analysis:			
Crude protein		12.32	8.26
Calcium		.42	1.18
Phosphorus		.35	.23

[1]Dry-matter basis.

[2]Ground by hammermill through a 1.9 cm screen.

[3]Guaranteed to contain not less than 96.0 percent sodium chloride, 0.25 percent zinc, 0.20 percent manganese, 0.125 percent copper, 0.005 percent iodine, and 0.005 percent cobalt.

[4]Supplied 2,200 IU vitamin A and 300 IU vitamin D per kilogram of diet dry matter.

The steers were weighed on 2 consecutive days at the beginning and at the end of the trial, with single weekly weights taken during the trial. All animals were housed on concrete lots with sawdust as bedding. Each diet was group-fed by self-feeders, with weigh-back from each feeder recorded and sampled for chemical analysis weekly.

Samples of the complete diets were oven-dried at 60°C, equilibrated to air temperature, and ground for laboratory analyses. Dry matter was determined

by oven-drying at 100°C, nitrogen by the Kjeldahl method, calcium by atomic absorption spectrophotometry (Willis, 1963), and phosphorus by the procedures of Harris and Popat (1954). A mineral analysis of the cement kiln dust used in this study was obtained from a commercial laboratory.[2]

Each pair of animals was slaughtered after both steers exceeded 450 kg average unshrunk weight. Weight, yield score, rib eye area, fat cover over the rib, carcass grade, and liver condemnations were recorded for each carcass. The empty rumen of each steer was weighed and visually examined for papillary clumping and epithelial color at slaughter. Heart, liver, kidneys, and spleen also were weighed and visually examined for gross physiological irregularities. Samples of ingesta were taken from the reticulo-rumen, abomasum, small intestine, and colon segments of the gastrointestinal tract and feces for pH determination. A general purpose combination electrode was used for all pH measurements.

All data were submitted to analysis of variance (Anderson and McLean, 1974), with significant differences between treatment means determined by Newman-Keuls Sequential Range Test (Keuls, 1952).

RESULTS AND DISCUSSION

Feedlot and carcass data are in table 2. There was no diet X time period interaction ($P>.10$) for any of the parameters measured, although steers fed the diet containing cement kiln dust tended to consume slightly more feed during the first 4 weeks of this trial.

Steers fed the cement kiln dust had a 27.9 percent (0.29 kg) higher ($P<.05$) average daily gain (ADG) and were 20.8 percent more ($P<.05$) efficient at converting feed dry matter to weight gain than those fed the control diet. These results are surprising since the control diet was formulated to satisfy all currently known dietary requirements for finishing steers (National Research Council, 1976), whereas the diet containing kiln dust was not. The 1.04 kg ADG for steers fed the control diet is similar to the 0.94 kg ADG reported by Oltjen et al. (1971) for steers fed comparable diets.

The data suggest not only a greater feed efficiency for steers fed cement kiln dust but also more desirable carcass characteristics (table 2). Steers fed the diet containing kiln dust had 0.7 cm more ($P<.05$) fat cover over the 12th rib and a higher ($P<.05$) marbling score. Furthermore, they graded higher ($P<.05$) than the control group. Carcass data for the control group were typical for steers fed this type of diet and agree with data of Oltjen et al. (1971). In general, the carcass data indicate that steers fed the cement kiln dust diet tended to deposit more fat than those fed the control diet.

[2]Analyzed by Lancaster Laboratories, Inc., 2425 New Holland Pike, Lancaster, Pa. 17601. This company is identified for the benefit of the reader and no endorsement of this service by the U.S. Department of Agriculture is implied.

TABLE 2.--Feedlot and carcass data of steers

Item	Diet	
	Control	Kiln dust
Feedlot performance:		
Number of steers	7	7
Number of days	112	112
Initial weight, kg	343	341
Average daily gain, kg	1.04a	1.33b
Average daily feed intake, kg	11.27	11.40
Feed/gain ratio	10.89a	8.62b
Carcass data:		
Carcass weight, kg	247	265
Dressing, percent	58.1	59.7
Rib eye area, cm^2	57.6	60.1
Fat over rib eye, cm	1.0a	1.7b
Grade[1]	6.4a	9.7b
Yield[2]	2.5	3.1
Marbling score[3]	6.8a	8.1b
Condemned livers, number	0	0

[1]Grade: 8 = choice, 5 = good.

[2]USDA yield grade.

[3]Marbling: 7 = moderate, 3 = small amount.

Note: Means on the same line with unlike letters are different ($P<.05$).

There were no differences in weight of internal organs between steers fed the two diets when expressed as a percentage of empty body weight (table 3). Visual examination of these tissues showed no apparent irregularities due to dietary treatment. The only readily visible difference resulting from the treatments was related to rumen color (table 3). Rumens from steers fed the cement kiln dust were noticeably ($P<.01$) darker than those from the control group. This observation probably had no influence on physiological function of the rumen since there were no treatment differences in either empty reticulo-rumen weight or papillae matting.

Gastrointestinal tract and fecal pH data (table 3) show that cement kiln dust was an efficient buffering material. Reticulo-rumen pH was increased ($P<.01$) from 6.21 to 6.80 by cement kiln dust addition to the diet. Steers fed the kiln dust also had a higher ($P<.01$) pH in the small intestine, colon, and feces, with pH values of approximately 6.9 compared with 6.4 for the control diet. Previous research (Wheeler and Noller, 1976) has demonstrated that pH values near neutrality are conducive to more efficient digestion in the gastrointestinal tract of ruminants. Consequently, the data show that cement kiln dust did maintain a more desirable gastrointestinal tract environment for digestion.

TABLE 3.--Characteristics of internal organs and gastrointestinal tract of steers

Item	Diet	
	Control	Kiln dust
	% EBW[1]	
Internal organ:		
Reticulo-rumen	2.51	2.38
Heart	.37	.39
Liver	1.35	1.27
Kidneys	.28	.25
Spleen	.18	.20
Gastrointestinal tract ingesta:	pH	
Reticulo-rumen	6.21d	6.80e
Abomasum	2.49	2.64
Small intestine	6.34d	6.89e
Colon	6.41d	6.85e
Feces	6.46d	6.97e
Rumen condition:		
Empty weight, kg	10.8	10.1
Papillae color[2]	1.8d	3.3e
Papillae matting[3]	1.6	1.4

[1] Internal organ weight expressed as a percentage of empty body weight.

[2] 1 = light, 4 = very dark.

[3] 1 = none, 4 = severe.

Note: Means on the same line with unlike letters are different ($P<.01$)

There is no immediate explanation for the response of finishing steers to cement kiln dust. Chemical analysis of the kiln dust shows that it is a complex blend of mineral elements (table 4). Several of these elements are known to be essential for ruminant animals (National Research Council, 1976) However, part of the response to cement kiln dust could be due to less well-known trace minerals which stimulate the growth of rumen micro-organisms. For example, Hubbert et al. (1958) and Bryant et al. (1959) have found trace minerals which are not required by the ruminant animal but are essential for maximum growth of several species of rumen micro-organisms.

Under present-day management practices, livestock are confined for long periods of time and have little access to soil. Ingested soil can be a source of several essential mineral elements (Healy, 1970) and can also affect availability of dietary elements in the digestive tract (Healy, 1972; Grace and Healy, 1974). Part of the response to cement kiln dust may be attributed to a mineral element(s) which under previous management practices for finishing beef steers was supplied through soil ingestion and consequent has not been considered essential.

Several characteristics of cement kiln dust also may contribute to part of the observed response in finishing steers. Kiln dust is different from most conventional mineral ingredients for livestock because of the extremely

TABLE 4.--Analysis of cement kiln dust

Item	Composition[1]
	Percent
Calcium	27.31
Phosphorus	.40
Sodium	.23
Potassium	.40
Magnesium	.52
Iron	1.11
Sulfur	2.33
Chlorine	1.10
Aluminum	4.16
	p/m
Copper	42
Cobalt	3
Zinc	145
Manganese	152
Selenium	17
Molybdenum	5
Chromium	110
Lithium	64
Strontium	15
Cadmium	4
Mercury	.5
Arsenic	7
Lead	124

[1]Dry-matter basis.

high temperatures (1500°C) to which it is exposed. These temperatures could increase the availability of several mineral elements to the animal. Likewise, the extreme fineness of the kiln dust could have some influence on mineral availability. Cement kiln dust has a particle size of less than 6 micrometers (Greening et al., 1973) and consequently an enormous surface area available for chemical reactions.

There is no single theory that will explain the growth response of finishing steers to cement kiln dust. Wheeler and Noller (1976) have shown that limestone buffer additions can improve digestibility of ruminant diets. We have calculated that no more than 40 percent of the observed response in the present experiment is attributable to such a buffering effect. Consequently, the buffering influence of kiln dust has been ruled out as a major factor. It is possible that the effects of cement kiln dust are due to the correction of a yet-unrecognized trace mineral deficiency which could be limited to certain geographical regions. Furthermore, although the effects of the cement kiln dust from Georgia were consistent in the trial reported here and